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REVIEW OF PROPOSED KAON FACTORY FACILITIES

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ABSTRACT

A number of proton accelerator facilities, popularly called "Kaon Factories," have been proposed to extend the intensity frontier from about 1 GeV to higher energies in the range of 15-45 GeV. Seven proposed facilities - LAMPF II, TRIUMF II, SIN II, AGS II, KEK, MUNICH, and KYOTO - are reviewed with emphasis on capabilities of the experimental facilities. Costs and the choice of energy and current are also discussed.

INTRODUCTION

For some time now, intermediate energy physicists have recognized the rich scientific opportunities that would be made accessible by extending the intensity frontier to higher energies. Present-day meson factories have demonstrated the immense scientific value of high intensity, high quality beams of protons, pions, muons, and neutrinos. The next clear step along this fruitful path is to add intense, high quality beams of kaons, antiprotons, hyperons, higher energy protons, pions, muons, and neutrinos to the facilities already available to the nuclear and particle physics community. Such a step requires a major commitment to a new generation of high intensity, higher energy facilities. Therefore, my purpose will be to describe the main features and the experimental capabilities of the new facilities proposed to meet these goals. However, I will not address further the important and interesting topic of physics justification, as it is beyond the scope of this paper.

OVERVIEW OF PROPOSED FACILITIES

Three basic design approaches can be identified in these proposals. In one, the plan is to increase the energy of an existing high-intensity machine by post-acceleration, as is the case for proposals from each of the meson factories, LAMPF II, TRIUMF II, and SIN II, where the post-accelerators, in each case, are rapid-cycling synchrotrons. In the second, the intensity of an existing high-energy machine is increased as proposed for AGS II and in some preliminary ideas for up-grading the 12 GeV PS at KEK. The third approach is to start from scratch and design a completely new complex where each component can be optimized for the final goal. The latter approach has been taken in a proposal for a "Kaon Factory" at Kyoto and in another proposal from a group at Munich.

The LAMPF II proposal in the first category is the most complete at this time.[1] A layout of the site plan for LAMPF II is shown in Fig. 1. The LAMPF linac, with its high peak intensity, is an ideal injector for a rapid-cycling synchrotron. It will soon accelerate an intense H^- beam in addition to the intense H^+ and polarized H^- beams.

The first use of high intensity H^- beam will be for injection into the newly completed proton storage ring (PSR) whose main function will be to provide pulsed beam to a spallation neutron facility. Twelve macropulses per second of the 120 Hz available will be used for PSR.

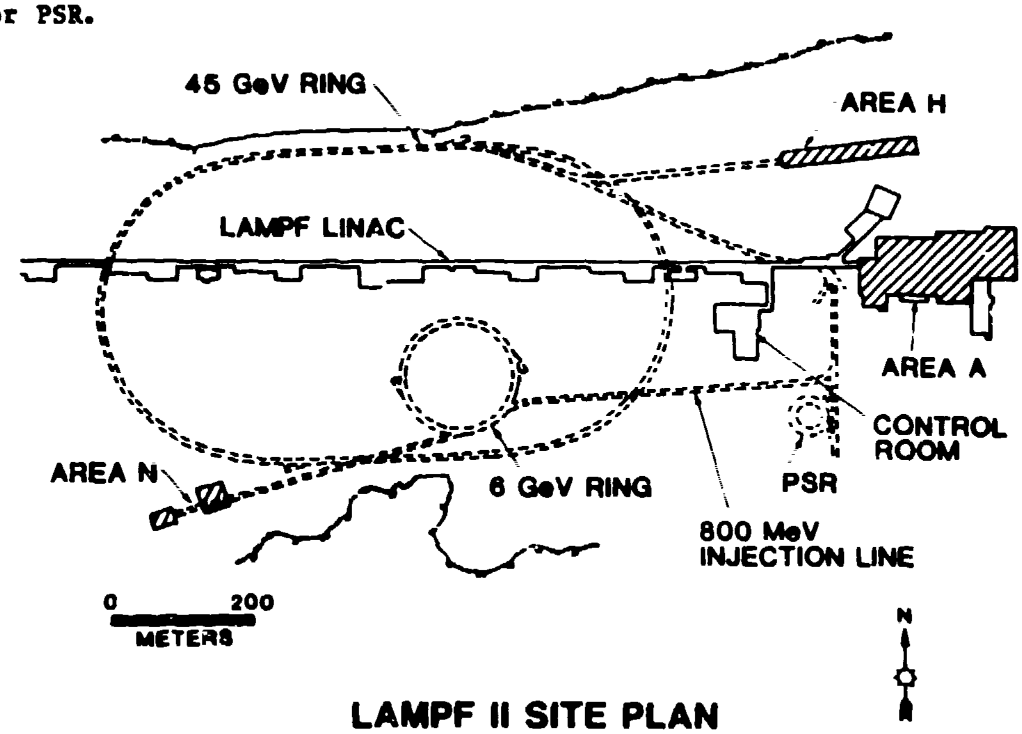


Fig. 1. Layout of LAMPF II.

For LAMPF II, 60 macropulses (1 ms in length) per second of H^- beam will be deflected into an 800 MeV injection line, transported to a booster, and injected via efficient H^- stripping into a 6-GeV rapid-cycling booster synchrotron, which would operate at 60 Hz. Fast extraction only is planned for the booster. Four booster pulses out of 20 would be injected into the main ring while the remaining pulses would be transported to a pulsed beam area, labeled Area N, which would have both neutrino and pulsed muon facilities. The main ring would be a rapid-cycling synchrotron operating at 3 Hz and would accelerate protons to 45 GeV. A flat-top on the magnet cycle would allow slow extraction from the main ring with 50% duty factor. The high-energy, slow-extracted beam would be split in a new high-energy switchyard into two simultaneous beams by use of a combination of electrostatic and magnetic septa. One beam would be transported to a reconfigured and extended Area A that would house two production targets and a number of low-energy secondary beam facilities. The other portion of the primary beam would be transported to a new high-energy area labeled Area H, which would contain the high-energy secondary beam facilities. All three experimental areas (A, H, and

N) would receive beam simultaneously with 800 MeV beam to PSR. In this mode 134 μA (average current) of 6-GeV beam is available for Area N while 34 μA (average) of 45-GeV beam is available for sharing in Areas A and H. Beam power on target is 0.8 MW for Area N and 1.5 MW for the high-energy beam for a total of 2.3 MW (average) for the three main experimental areas. The micro-structure of the 45-GeV beam consists of pulses about 2-ns wide separated by 16.7 ns.

With fast extraction it is possible to operate the 45-GeV main ring at 6 Hz and thereby deliver 68 μA (average), for example, to the neutrino area for production of higher energy neutrinos. A 45-GeV stretcher ring can be added to the main ring tunnel as a future option to provide 68 μA with 100% duty factor to the slow-extracted beam areas.

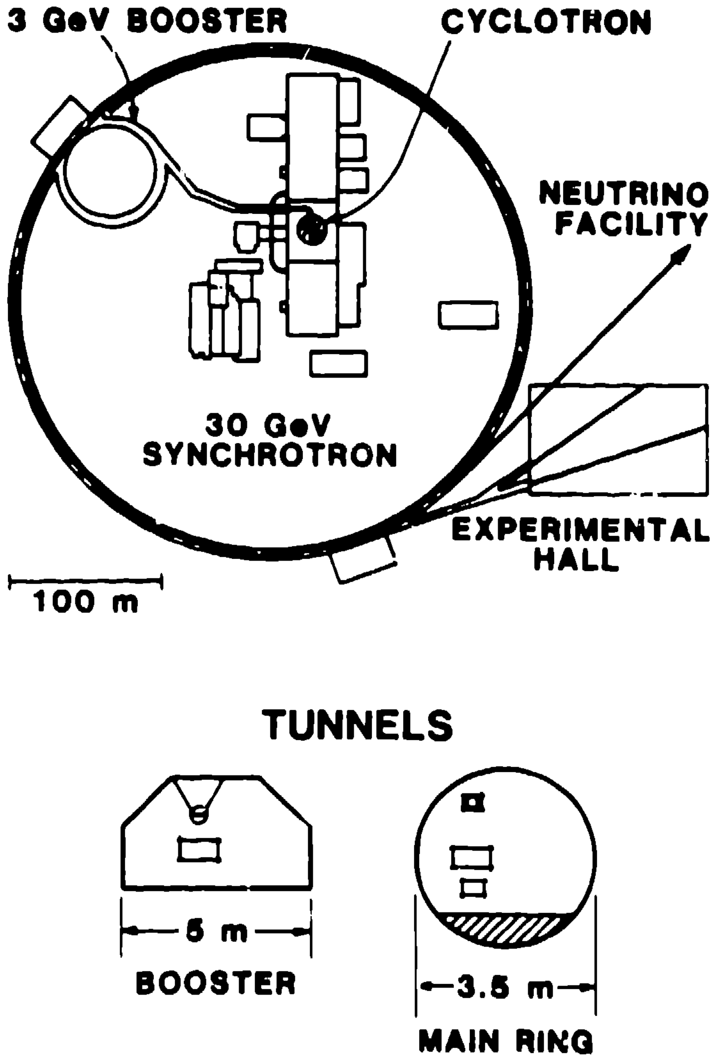


Fig. 2. Plan for TRIUMF II.

The TRIUMF II[2] and SIN II[3] proposals make use of existing cyclotrons as injectors. Because the essentially CW time structure of cyclotrons is not well matched to a synchrotron, an accumulator stage is added to compress the beam and provide an ideal time structure for single-turn injection into the synchrotron.

The proposed site-plan layout for TRIUMF II is shown in Fig. 2. The existing TRIUMF cyclotron would be modified to permit extraction of H^- at 440 MeV so that it can be injected via stripping into an accumulator ring housed in the 3 GeV booster tunnel. After the accumulator is filled, it is emptied in a single turn into the booster synchrotron that then accelerates to 3 GeV at a 50 Hz rate. The large-circumference main-ring tunnel houses three rings, one above the other, and descriptively named the collector, the driver, and the extender, respectively. After five booster pulses are accumulated in the collector, it is emptied in a single turn into the driver synchrotron, which accelerates the beam to 30 GeV at a 10 Hz rate. The 30-GeV beam, which is extracted from the driver in a single turn, can be transported directly to the pulsed neutrino facility or injected into the extender, which functions as a stretcher ring to provide slow spill with 100% duty factor to the main experimental area. The slow extracted beam is split by a combination of rf deflection and electrostatic and magnetic septa into as many as four separate primary beam lines in the main experimental hall. One bonus from the rf deflection is a doubling of the separation between micropulses to 32 ns, which is advantageous for certain time-of-flight applications. TRIUMF II will provide 100 μA (average) beam at 30 GeV for a total of 3 MW of beam power on target.

An upgrade of the SIN facilities to 2 mA is currently underway. For SIN II, a portion of this beam would be deflected to a complex of post accelerators as shown schematically in Fig. 3. The deflector, operating at 3 kHz, provides a train of 590-MeV beam pulses 30-μs wide separated by 0.33 ms to a combined accelerator and storage ring, ASTOR. This unique interface is an isochronous cyclotron that accelerates beam to 1.3 GeV and permits stacking of 120 ASTOR turns at the extraction radius through the so-called phase-expansion process. A fast kicker extracts the stack in a single turn. In order to reduce extraction losses, a 70 ns void is created by deflecting 3 out of 12 micropulses with an rf deflector before injection into ASTOR. The 170-ns long ASTOR pulses are parked in an accumulator ring in the main-ring tunnel. The accumulator is actually four rings, one on top of the other. It can store 60 (4x15) ASTOR pulses, which are then merged and transferred into 15 "boxcars" of the 50 Hz rapid-cycling synchrotron. After acceleration to 20 GeV, the beam is extracted in a single turn for use in a neutrino area or injected into a stretcher ring for slow extraction to the main experimental area. The micropulse structure at 20 GeV is 1-2-ns wide pulses separated by 18 ns. The average beam intensity at 20 GeV is expected to be about 80 μA, thus providing 1.6 MW of beam power on target. Some thought is being given to increasing the final energy to 30 GeV.

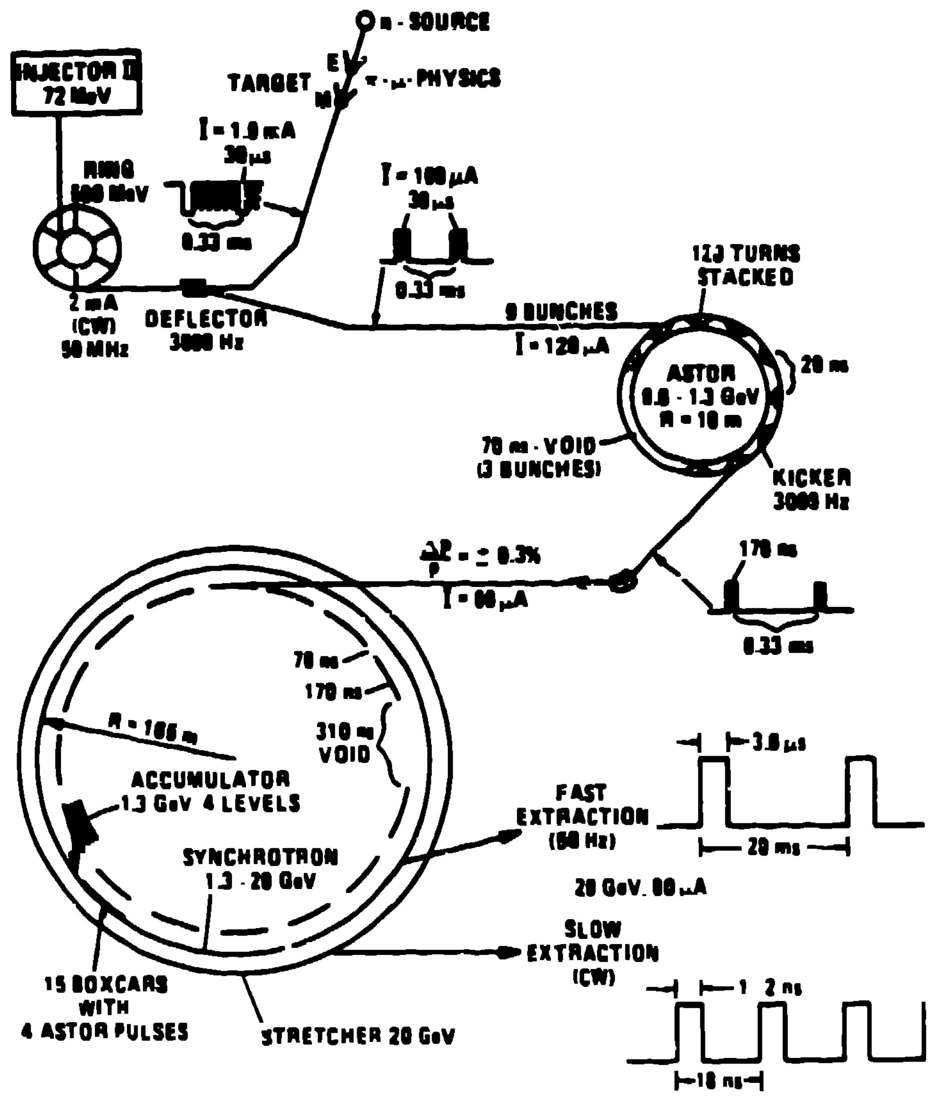


Fig. 3. SIN II Schematic layout.

AGS II[4] is the name given to a collection of improvements designed to increase the intensity of the venerable AGS by an order of magnitude or more as well as improve operational reliability. One of the most important improvements would be the addition of a booster synchrotron to raise the space-charge limit of the AGS. The lowest energy (and least expensive) booster being discussed is 1 GeV and is thought to be good for a factor of four increase in intensity. Such a booster is also needed for the heavy-ion program sought at BNL. A number of improvements resulting from increased effort on machine development studies can be expected to yield modest increases in intensity and improved reliability. A future site plan for the AGS is shown in Fig. 4. Included are the booster and transfer lines for the heavy ion program.

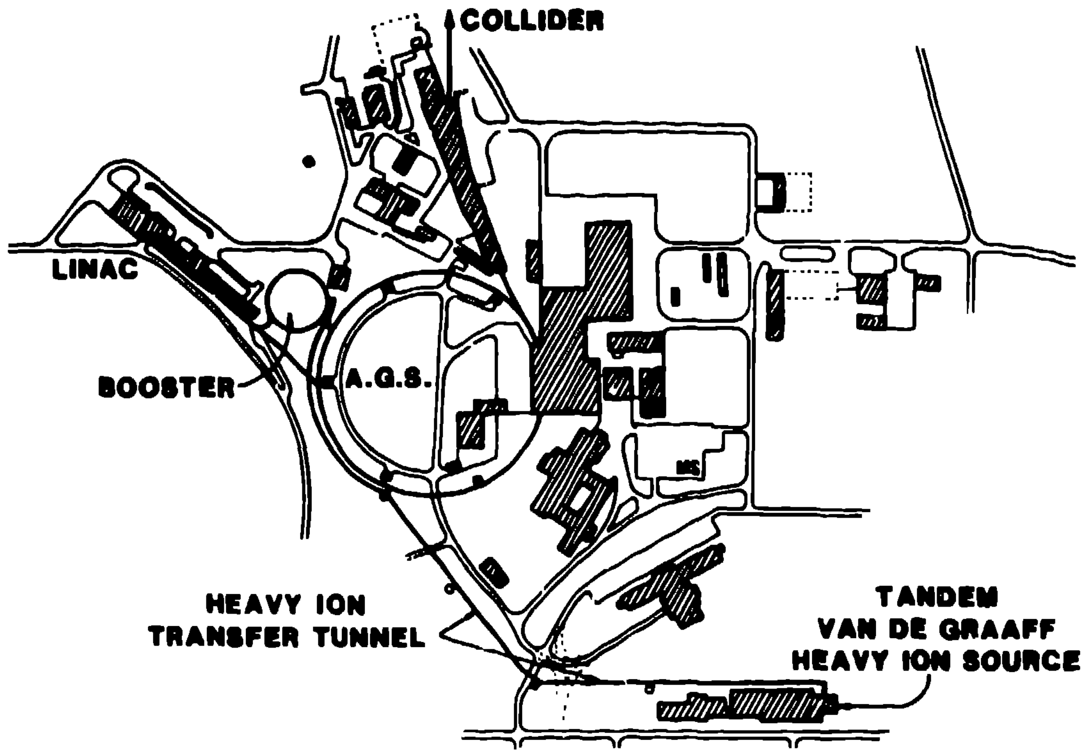


Fig. 4. AGS II Site Plan.

In a second phase, the addition of a 30-GeV stretcher ring to the AGS tunnel would allow the AGS to operate at nearly a factor of two higher repetition rate for a corresponding increase in intensity while at the same time providing 100% duty factor for the slow-spill beam users. A third phase has been discussed in which the booster energy is increased to 2.5 GeV, further increasing the space-charge limit of the AGS. To handle the increased intensity, the rf system of the AGS would need to be replaced while major upgrades are needed for the vacuum and controls systems. At some point, improvements to the experimental areas would be needed to properly handle and exploit the increased intensity. Principal beam line improvements to the slow-extracted beam area could be the addition of a high acceptance, good resolution 1-2 GeV/c kaon beam line, time separated and time purified antiproton beam, and external heavy-ion beams. Improved target cooling, additional shielding, additional radiation hardening of components, and remote servicing capabilities are probably needed for higher intensity operation.

Many of the AGS II ideas are documented in the AGS II Task Force Report submitted to the BNL management.[4] Further evolution of priorities has taken place since that report. Basically, BNL management gives its highest priority for new construction to the Relativistic Heavy Ion Collider, RHIC. The 1-GeV booster would allow the AGS to accelerate heavy ions and, as such, is an important precondition for RHIC. It has been proposed to the funding agencies.

A future plan of the KEK[5] site is shown in Fig. 5. GEMINI is a proposed rapid-cycling 800 MeV synchrotron that would provide 500 μA of protons to an intense spallation neutron source, KENS-II, and to an extension of the meson science facilities, Super BOOM. A kaon factory might be achieved by using GEMINI as an injector for another higher-energy ring such as the 12-GeV PS. Its circumference has been chosen to be half that of the 12-GeV PS in order to allow for such a possibility. The PS would require modifications to handle high intensity. Another possibility might be a 30-GeV superconducting ring in the present 12-GeV PS tunnel. These and other possibilities will be looked at in more detail in the near future.

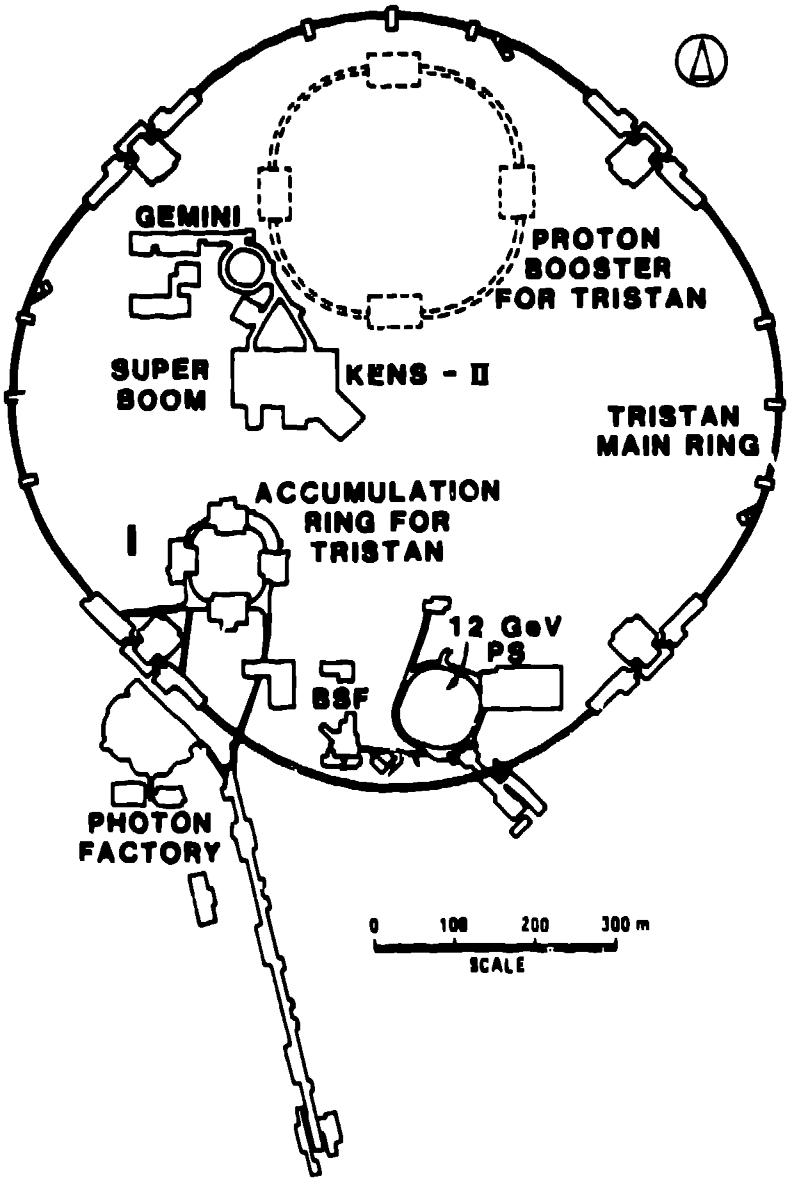


Fig. 5. Future Site Plan for KEK.

A group from Munich[6] has proposed an ambitious kaon factory that would deliver 500 μA of protons at 30 GeV. Its layout is shown in Fig. 6. The first stage is a slightly enlarged version of the SIN Injector II cyclotron delivering 5 mA of protons at 100 MeV, which are then injected into KISS, a 2.5-GeV superconducting isochronous sector cyclotron. Most of the beam from KISS (80%) would be delivered to a nearly CW spallation neutron source (CNS). The remaining 20% of the beam from KISS is delivered in 2 ms pulses for multiturn (900 turns) injection into an accumulator ring (ACC) that is one of three rings in the main ring tunnel. Half (50) of the accumulator pulses are ejected to a pulsed spallation neutron source (PNS) and the other half are injected into a 50-Hz, 30-GeV rapid-cycling synchrotron (RCS) in the same tunnel. The third ring in the main ring tunnel is a 30-GeV stretcher ring to provide slow extracted beam with 100% duty factor to meson and antiproton experimental areas. This proposal is not active at the present time; the proponents have turned their attention to other projects.

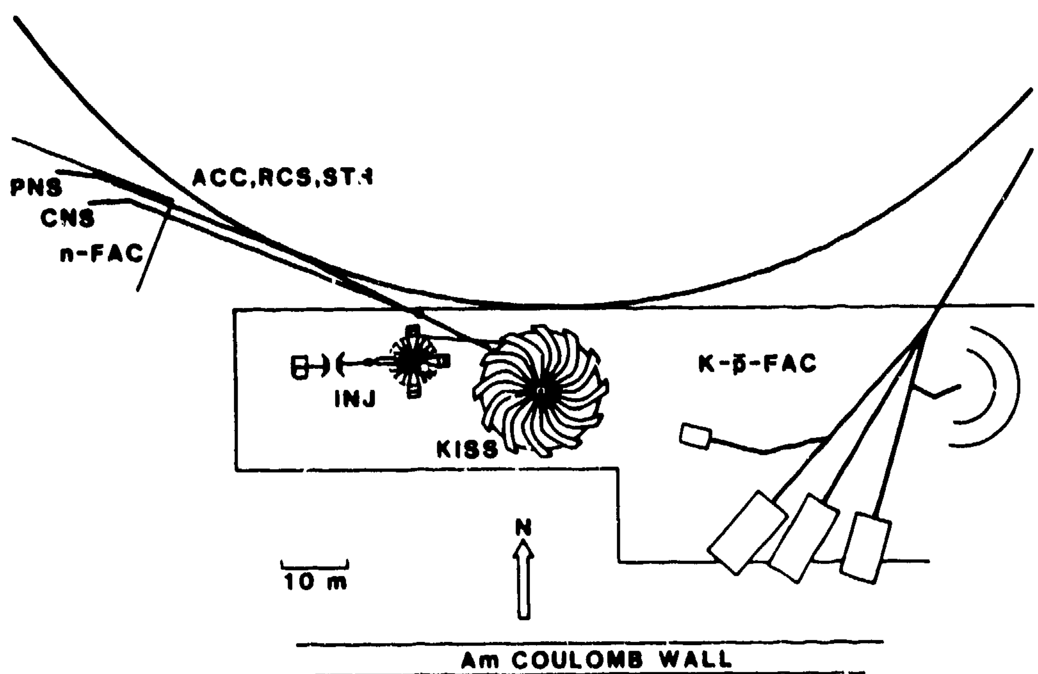


Fig. 6. Munich kaon factory plan.

The seventh proposal to be discussed is from a group at Kyoto[7] University where they want to build a high-intensity accelerator complex for meson science. A plan view of the proposed facilities is shown in Fig. 7. The latest version of their plan calls for an 800-MeV linac, a 25-GeV rapid-cycling synchrotron, and a stretcher ring. Additional options being considered are an 800-MeV compressor ring and an antiproton accumulator ring.

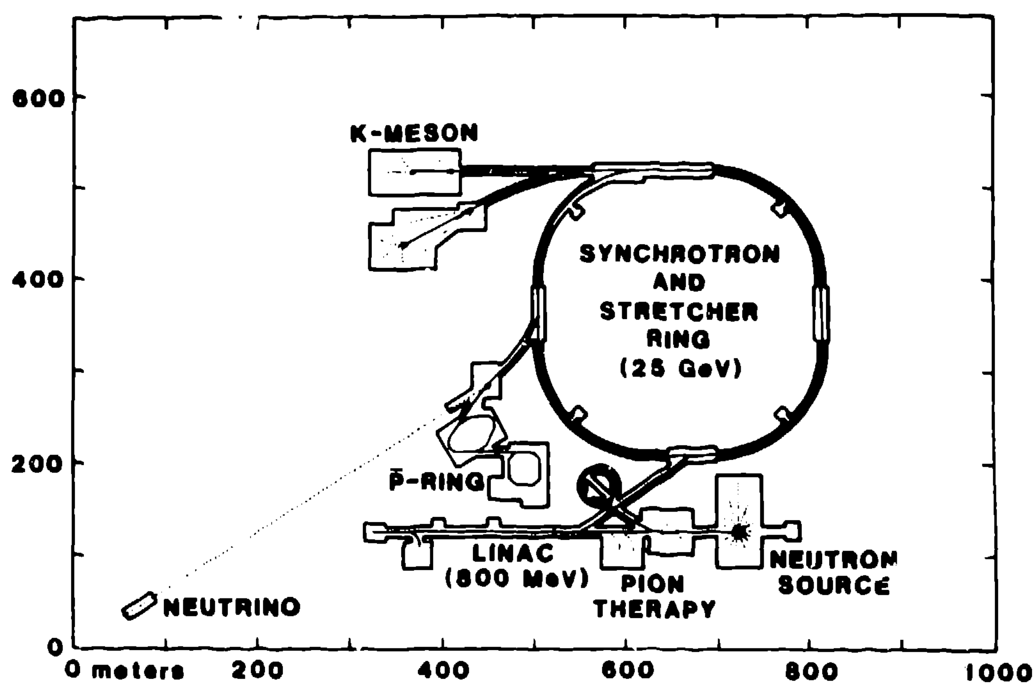


Fig. 7. Proposed facilities at Kyoto.

The linac is based on the PIGMI design and would be smaller, less intense, and less expensive than the existing LAMPF linac. It would consist of a 2.5-MeV RFQ, a drift-tube linac of 115 MeV, and a coupled-cavity linac of 800 MeV. It will be capable of simultaneously accelerating 100 μA each of H^+ and H^- at 60 Hz. The H^+ beam is used directly for a spallation neutron source, pion radio-therapy, and isotope production. The H^- beam is used for injection directly into the 30-Hz rapid-cycling synchrotron as well as for injection into the compressor ring.

Since the 25-GeV synchrotron operates at 30 Hz, the remaining 30 Hz of H^- is available for the compressor where the time structure will be compressed from 20 μs to a few hundred ns. This can be used for pulsed neutron and pulsed muon beams. Another use for the compressor is for antiproton accumulation. Here the compressed beam is transferred to the main ring, accelerated and extracted as a pulsed beam whose length is the same as the circumference of the accumulator ring. The short pulse of protons could also be used to provide pulsed neutrino beams. A stretcher ring is located in the main ring tunnel and provides slow spill with 100% duty factor to the K-meson area.

A summary of the main parameters for the seven proposed kaon factories is given in Table I below, including a comparison with the today's standard, the AGS at BNL. Also included is a brief indication of proposal status. LAMPF II, so far, is the only proposal submitted to the funding agencies. TRIUMF II, SIN II, and the KYOTO proposals are actively being developed with a formal proposal expected shortly from TRIUMF. The status of AGS II is more

Table I. Main parameters for proposed kaon factories.

	ENERGY (GeV)	CURRENT (μA)	BEAM POWER* (MW)	DUTY FACTOR# (%)	PROPOSAL STATUS
LAMPF II	45 +(6)	34 (134)	2.3	50%	PROPOSED & SUBMITTED FEB '85
TRIUMF II	30	100	3.0	100	ACTIVELY BEING DEVELOPED
SIN II	20	80	1.6	100	UNDER DEVELOPMENT
AGS II	30	~ 10-27	0.3-.9	100	HEDG REPORT
KEK	12 or 30	~ 10 ?	?	?	IDEA
MUNICH	30	500	15	100	IDEA
KYOTO	25	50	1.25	100	UNDER DEVELOPMENT
AGS (today)	30	0.8	0.024	50%	EXISTING MACHINE

*Beam Power on Targets
#Duty Factor for Slow Extracted Beam

ambiguous given the top priority assigned RHIC by the BNL management. The proposal from Munich is not currently active. The ideas for a kaon factory at KEK may get more serious consideration in the near future.

CHOICE OF ENERGY AND CURRENT

Many complex factors - physics, costs, reliability - influence the choice of energy and current. It is one of the most important choices made by proponents of a kaon factory. I will give the arguments for the LAMPF II choices; others have considered many of the same points but sometimes reach slightly different optimizations that are tailored for their particular circumstances. For the basic LAMPF II design we find that, over the range of interest, costs are more strongly correlated with beam power than with either energy or current alone. To first approximation, the costs are fixed by choice of beam power. Given a fixed beam power we were driven to higher energy and correspondingly lower current for two reasons. From the point of view of accelerator technology, it is easier and more reliable to achieve beam power with higher energy than higher current. Problems of beam stability are less at lower current.

The second reason has to do with two physics arguments. One is the general perception that QCD effects in nuclei are more likely to be understood with a range of probes, including higher-energy probes, than with only lower-energy probes. The other is the observation, illustrated in Fig. 8 for K^- production, that low-energy beam rates will not suffer and the higher energy, secondary beam rates will be significantly enhanced by using a higher, primary beam energy even though the current is proportionally lower. In Fig. 8 the forward (0^o) K^- yield per interacting proton divided by incident proton kinetic energy, essentially the yield per unit of interacting beam power, is plotted as a function of primary beam energy over the range 10 to 70 GeV for several values of the secondary beam momentum. For

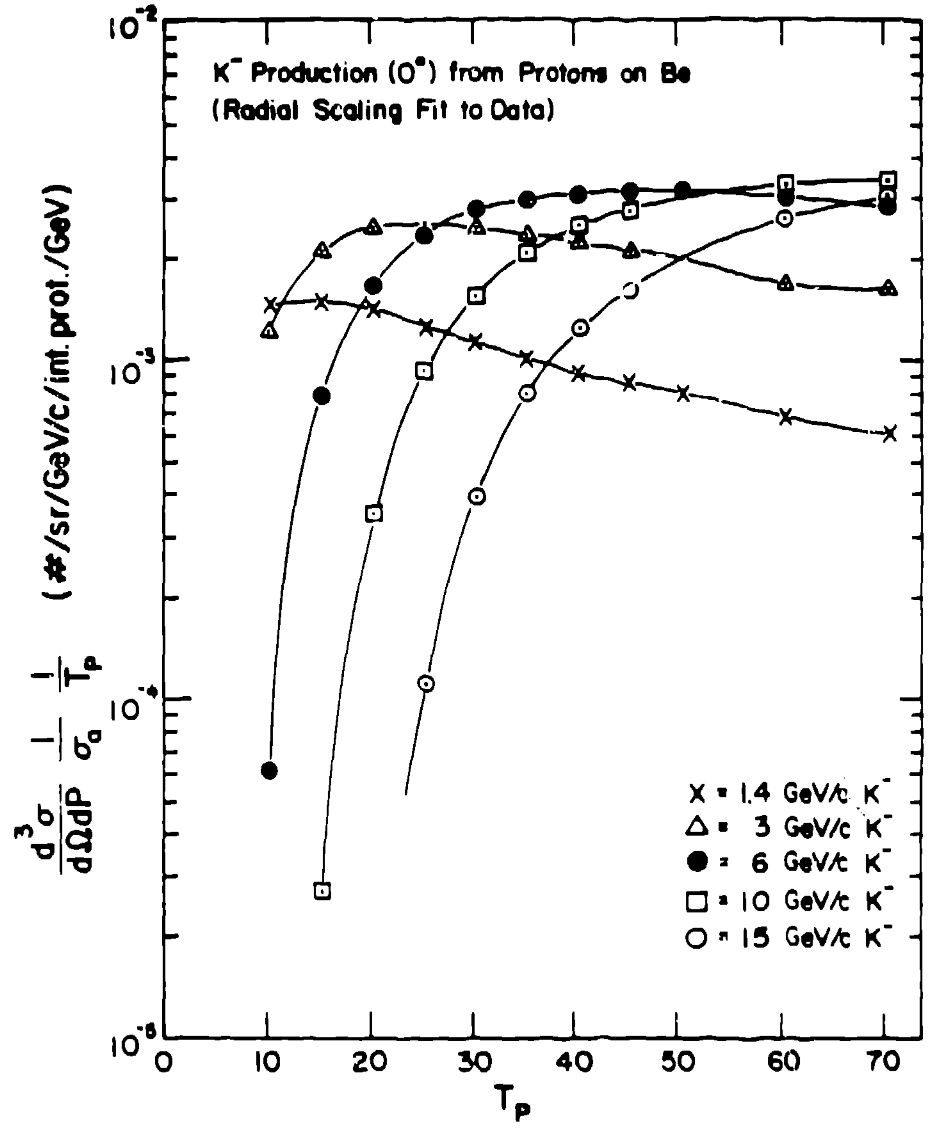


Fig. 8. K^- yield per unit of interacting beam power.

the lower-energy secondaries the curves are flat over the region of interest while the higher-energy curves plateau at successively higher primary-beam energies. Thus, the LAMPF II choice of 45 GeV primary-beam energy insures a high yield of 15 GeV/c K^- without significant reduction of the low-energy beam rates. Similiar arguments and data hold for antiproton production.

Much the same reasoning holds for neutrino beams. In Fig. 9 we have plotted the relative ν_μ-e counting rate per unit of incident beam power, $([\int \text{Flux } E_\nu]/E_\nu)^\mu$, a function of incident proton momentum for a typical neutrino beam and detector. After the knee of the curve, which occurs near 7 GeV/c, the counting rate is essentially flat, thus a function only of beam power. The LAMPF II booster momentum of 7 GeV/c, which was chosen primarily for reasons of accelerator efficiency, also turns out to be optimal for a low energy neutrino facility.

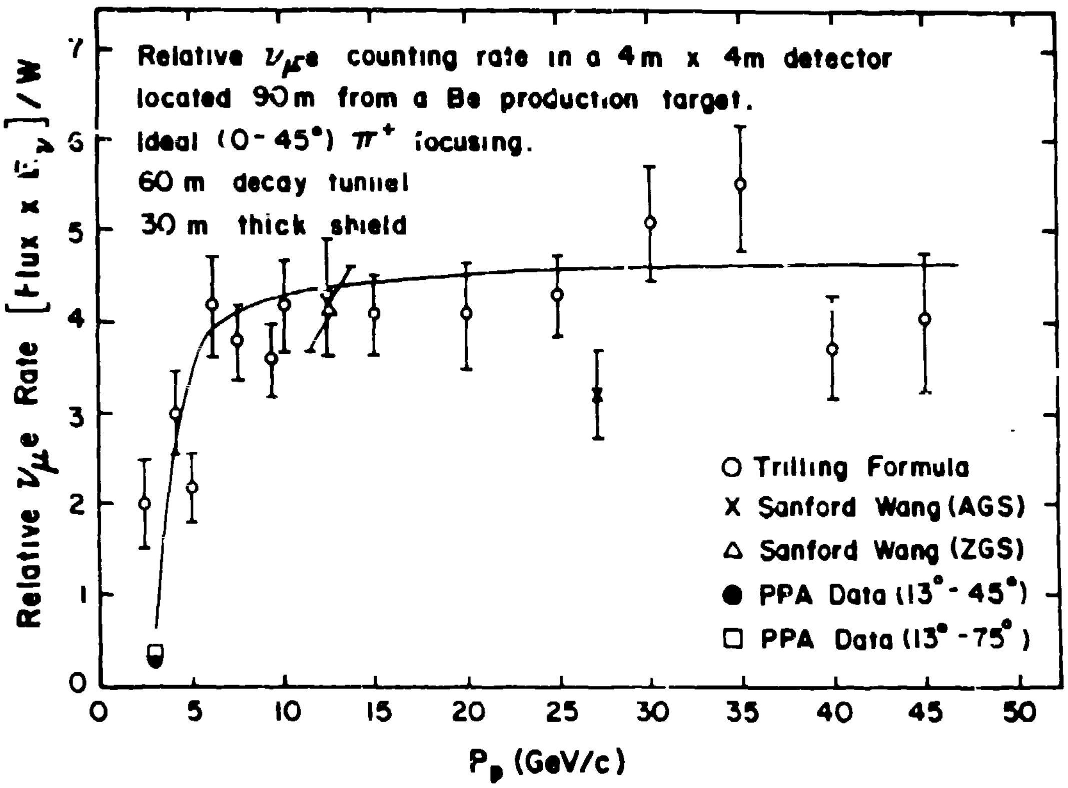


Fig. 9. Relative ν_μ-e rate per unit of incident beam power.

CAPABILITIES OF THE EXPERIMENTAL AREAS

For most experimenters the capabilities of the experimental facilities are of paramount importance. I will concentrate on the LAMPF II areas since they are the most complete at this time and are fairly representative of what can be done at a kaon factory. The goals for LAMPF II are to provide a number of high-intensity, high-quality beam lines. By high quality, I mean such factors as high purity, good energy resolution, and good spatial definition; in fact, high brightness in all six dimensions of phase space is highly desirable. We want to run many experiments simultaneously while at the same time maintaining a highly reliable operation. Therefore we propose 10 simultaneous high-intensity secondary beam lines covering a broad range of energies and species that can all operate and deliver beam at the same time.

To achieve these goals requires, first and foremost, a strong capability to handle high intensity. The successful experience at LAMPF with 1 mA beam and the experience at the other meson factories with high-intensity beams is directly applicable to LAMPF II. We have mastered the problems of reliably cooling high-intensity targets and nearby components. We have proven designs for radiation-hardened beam line components and we have proven capabilities for remote servicing of these components. Throughout the design process we have given careful consideration to developing cost-effective solutions. I will point out some specific ones later.

EXPERIMENTAL AREA N

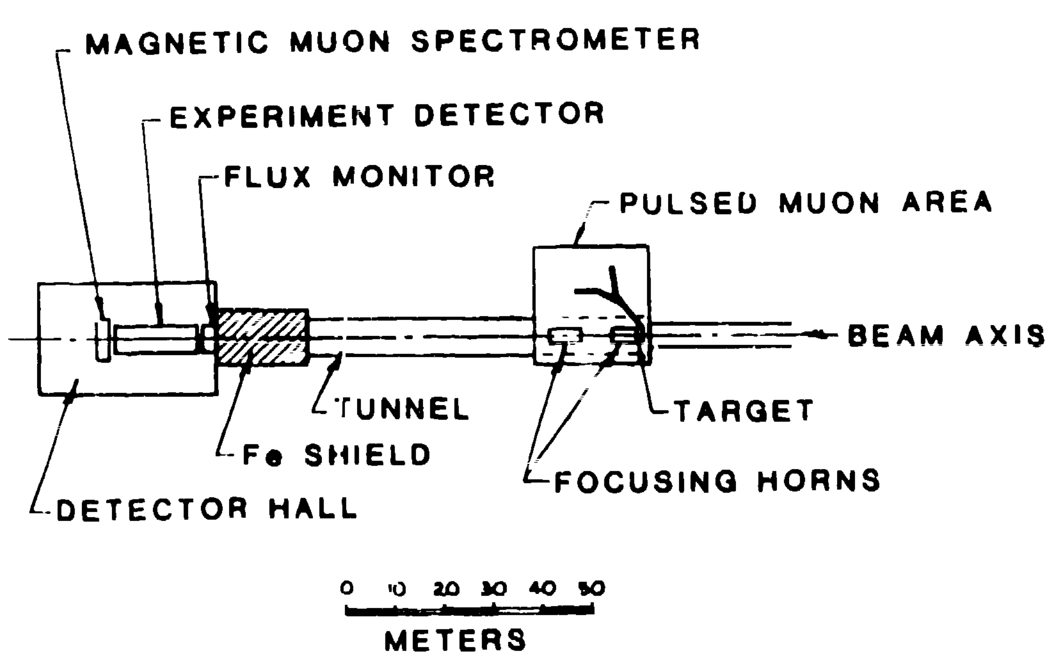


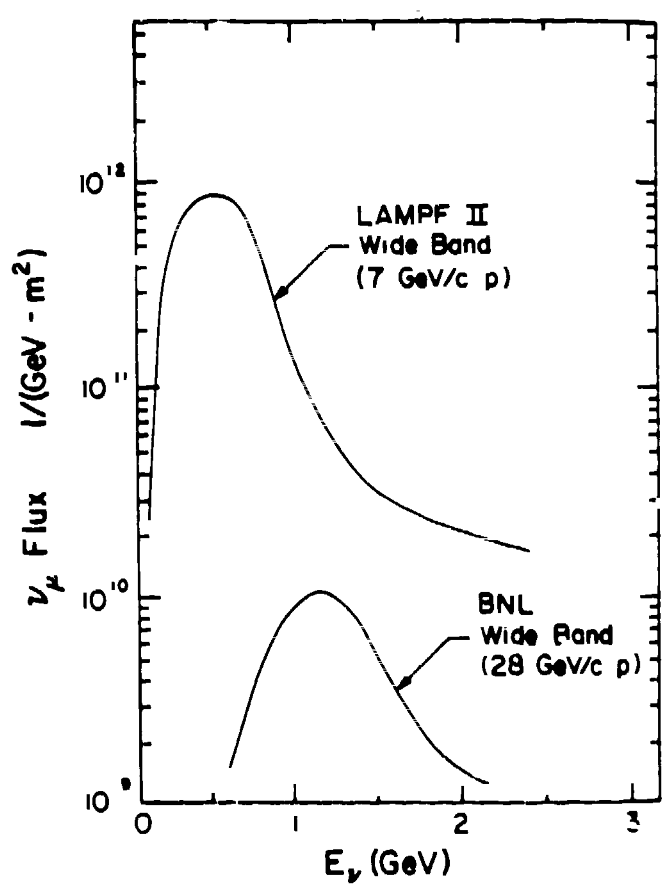
Fig. 10. Area N layout for LAMPF II.

One new technology needed for LAMPF II is high-duty-factor rf separators. These are needed to purify the kaon beams above about 6 GeV/c and antiproton beams above 9 GeV/c. Superconducting rf cavities show much promise in this area. It is an option we want to pursue for LAMPF II.

Area N at LAMPF II is shown schematically in Fig. 10. It will receive 6 GeV pulsed beam from the booster and will contain pulsed neutrino and pulsed muon beams. The primary beam strikes a long graphite production target partially enclosed by the first horn of a two-horn pion focusing system. From the focusing system, the pions drift into a decay tunnel. The shielding at the end of the tunnel removes all but the neutrinos that pass into the detector hall. A muon channel views the first few cm of the target and in this way can operate at the same time as the pion focusing horns. Area N is all below grade to minimize shielding costs. Access to the targets and focusing horns is vertically through high-density shielding that permits use of LAMPF standard remote-handling equipment when necessary for remote maintenance.

Calculations of the neutrino flux spectrum have been made for the LAMPF II neutrino facility; they show that it will be the world's highest-intensity neutrino factory by a wide margin. Results for the ν_μ spectrum are plotted in Fig. 11. Also shown for comparison are

Fig. 11. LAMPF II neutrino flux spectrum.



results for the wide-band beam at today's AGS using 28 GeV/c incident protons. The LAMPF II neutrino flux is about a factor of 100 higher in intensity and peaks at factor of two lower energy. For $\nu - e$ scattering and neutrino-oscillation experiments, the lower energy is more desirable.

Beam line parameters and rates for the pulsed muon channel are shown in Table II below.

Table II. Pulsed muon channel parameters.

Target = 40 mm graphite	$\Delta\Omega_\pi$ = 42 ms
5m long solenoid	$\frac{\Delta P}{P}\pi$ = 16%
π^- rate into solenoid	I_p = 170 μA
= 7.6 + 10^9/s	
μ^- Rate at output = 2.4 x 10^8/s	

The low-energy secondary beams will be housed in Area A as shown schematically in Fig. 12. A fraction of the 45 GeV beam from the switchyard is transported to Area A where it strikes two targets, A-1 and A-2, in sequence. The remaining primary beam then drifts to a beam stop. The first target of about 1/2 interaction length in

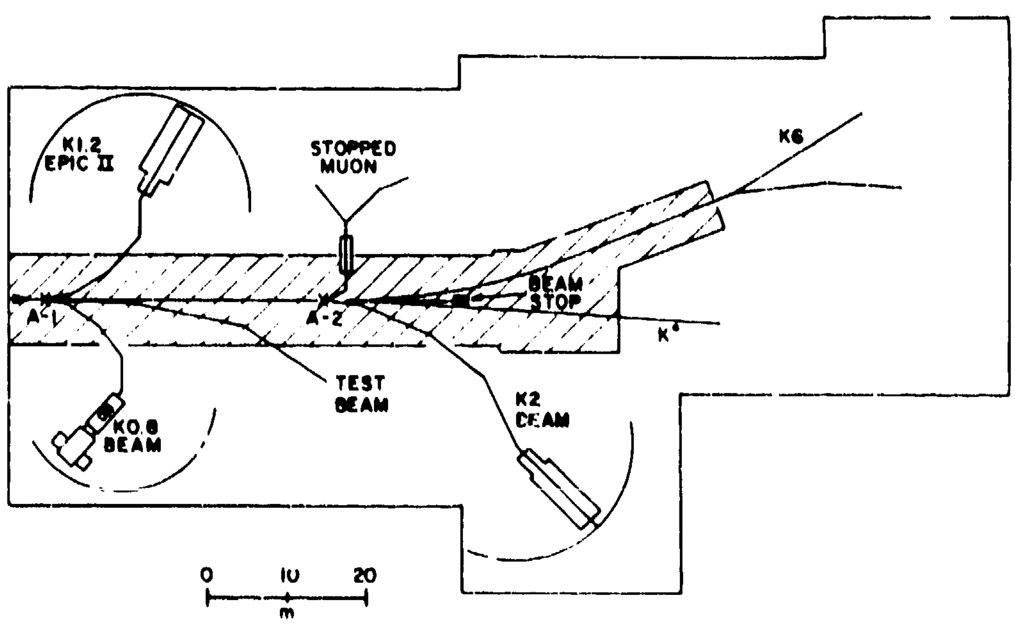


Fig. 12. Area A layout at LAMPF II.

thickness is viewed by two low-energy kaon beam lines complete with spectrometers whose energy resolution is suitable for nuclear structure studies. The number following the K in the name refers to the maximum momentum kaon transported by that beam line. A general purpose test beam also receives beam from the first target. The second target of about one interaction length thickness provides beam to two general-purpose charged kaon beam lines, K2 and K6, a neutral beam (K^0), and a stopped muon channel.

The three lowest-energy charged kaon beams will each have two stages of DC separation to insure good beam purity. One stage of separation is sufficient for K6. While each of the charged kaon beams has been optimized for kaons of the maximum momentum transported by that channel, they are also, in fact, first-rate pion and antiproton beams. In all, Area A will house six high-intensity secondary beams plus one test beam, all of which can operate simultaneously.

The LAMPF II secondary beam lines have not been designed in detail. Instead, the most important features have been deduced from general principles in a "top down" fashion. One critical region receiving the most attention so far is the first section of beam line in the target cell. In general, this section has the most design constraints including the need for special cooling, radiation hardening, remote servicing, and the geometrical constraints of fitting in two large-acceptance, forward, charged, secondary beam channels along with a channel to allow passage of the remaining primary beam. The beam line beyond the target cell region can be of a more conventional design using more conventional components.

One design for meeting the target cell constraints is shown in plan view in Fig. 13. The downstream magnets are protected from the high heat and radiation load of scattered beam by a water-cooled copper collimator that absorbs 80-90% of the scattered beam power

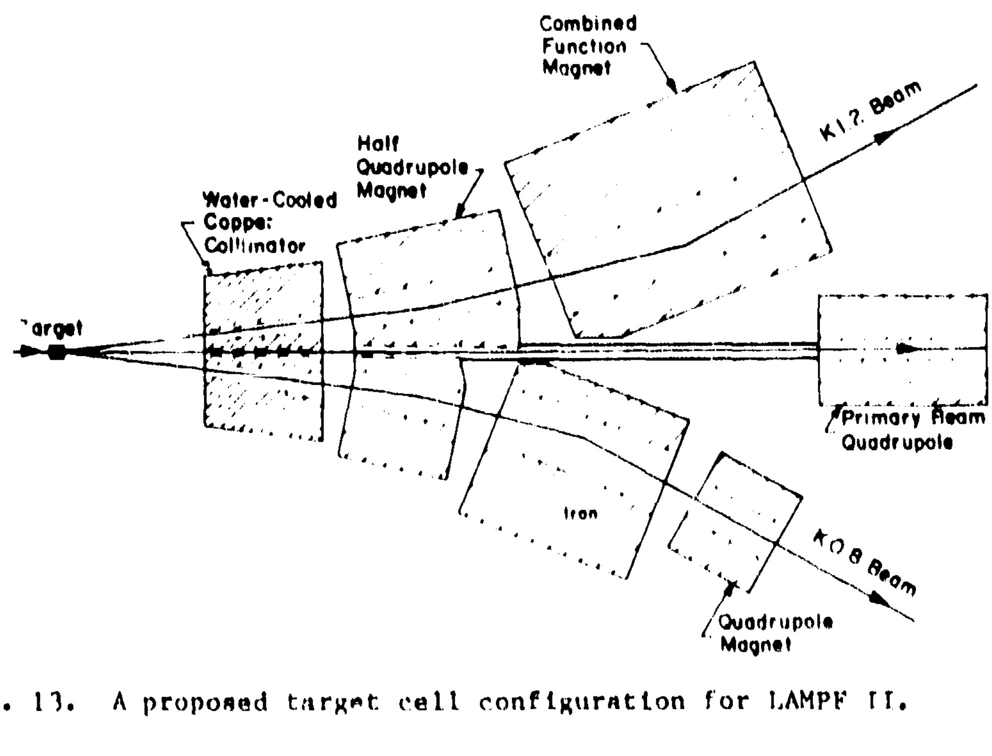


Fig. 13. A proposed target cell configuration for LAMPF II.

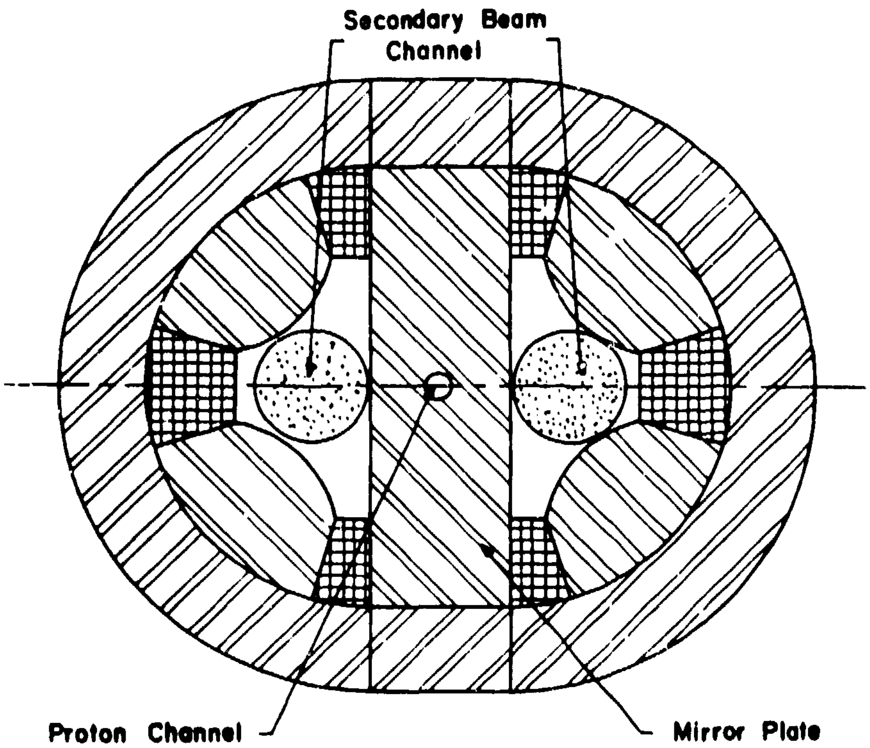


Fig. 14. Cross section of half-quadrupole pair in target cell.

incident on the collimator. Half-quadrupoles and other combined function magnets provide the necessary bending and focusing of the secondary beam with the least geometrical interference. A cross-sectional view of the half quadrupoles in a plane perpendicular to the primary beam is shown in Fig. 14. A hole in the mirror plate provides a field-free channel for the primary proton beam.

High-energy secondary-beam facilities are desired for LAMPF II. These would be housed in a new experimental area, H, shown very schematically in Fig. 15. A portion of the 45-GeV primary beam is transported to this area, which is below grade to reduce shielding costs. The first target serves a double-armed spectrometer facility that, in the configuration shown in Fig. 15, could be used to study

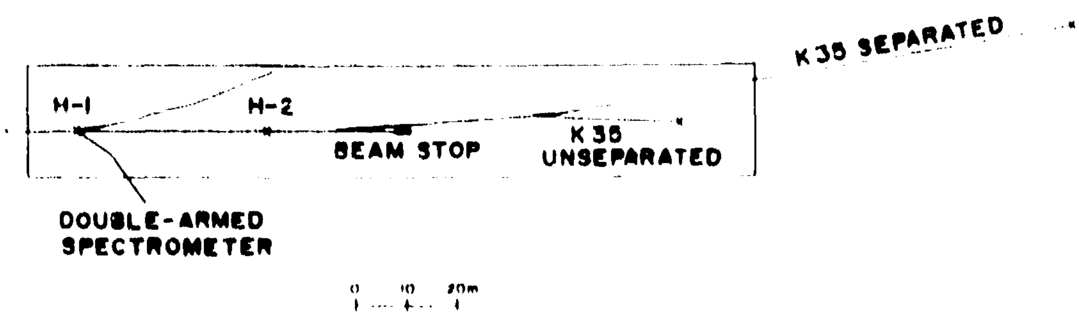


Fig. 15. Schematic layout of Area H at LAMPF II.

high P_t events in p-p interactions. Another configuration of spectrometers could be used to study high-energy muon pairs from the Drell-Yan process. The second target provides secondary beam particles to a zero-degree, general-purpose, high-energy beam, K35. It would have two branches; one branch would have high acceptance and be unseparated while the other low-acceptance branch would have beam purity enhanced by the use of high-duty-factor, superconducting rf separators. Both facilities in Area H could take beam simultaneously.

The important parameters for the LAMPF II secondary beams are summarized in Table III below. The maximum beam rates in the last column are estimated assuming that all of the 45 GeV beam strikes the target for the beam line being considered except for the pulsed muon and neutrino beams where the rates are for 134 μA of 6-GeV beam on target.

Table III. LAMPF II secondary beamline parameters.

	p (GeV/c)	ΔΩ (MSR)	$\frac{\Delta p}{p}$ (%) (Res.)	$\frac{\Delta p}{p}$ (%) (Bite)	Length (m)	Max Beam Rates
K0.8 Hyper-Nuclear & Stopped Kaon	0.4–0.8	5	0.1	5	18	10^7 (K^-)
K1.2 + EPICS II	0.7–1.2	2	0.05	3	25	10^7 (K^-)
K2 + Spectrometer	1.0–2.0	1.0	0.5	5	35	$3 \cdot 10^7$ (K^-)
K6 General purpose	2-6 K 2-10 P	0.07	1.0	5	75	$5 \cdot 10^7$ (K^-)
K^0	Wide-band	0.05	TOF	Wide-band	40	$2 \cdot 10^9$ (K^0)
K35 Unseparated branch	up to 35	0.5	1.0	5	85	10^9 (K^-)
K35 Separated Branch	up to 35	0.05	1.0	1	~ 190	$6 \cdot 10^6$ (K^-)
Stopped Muon	0.2	42	5.0	15	~ 20	10^9 (μ^-)
Test Beam	up to 15	0.1	~ 1.0	~ 3	~ 40	~ 10^7 (K^-)
Pulsed Muon	0.2	42	5.0	15	~ 20	$2 \cdot 10^8$ (μ^-)
ν Beam	~ 0.8	--	--	Wide-band	~ 60	$3 \cdot 10^{12}$ (ν_μ)

I want to summarize the expected performance characteristics of these beam lines. For many users the single most interesting characteristic would be the K^- beam rates. These are shown as a function of kaon momentum in Figs. 16 and 17 under typical operating conditions where all beams are operating simultaneously, all production targets are in the beam, and the primary beam is split equally between Areas A and H. The rates range from 10^4 to 10^8 per second. The large difference between the separated and unseparated branches of K35 is due to the reduced acceptance of the separated branch caused by the limited aperature of the rf separators. Also shown, for comparison, are a few points for today's K^- beams at BNL. LESB I, LESB II, and MESB are single-stage separated beams. Note that C1 is an unseparated beam; there is no high-energy separated beam at BNL for comparison. In general, the LAMPF II beams are a factor of 100 higher except at the very low momentum end where the extra length, due to two stages of separation, results in significant decay losses. This is the price paid for higher purity. At the high-momentum end of the spectrum, the LAMPF II advantage is even greater and is a result of the higher primary beam energy as well as the higher intensity.

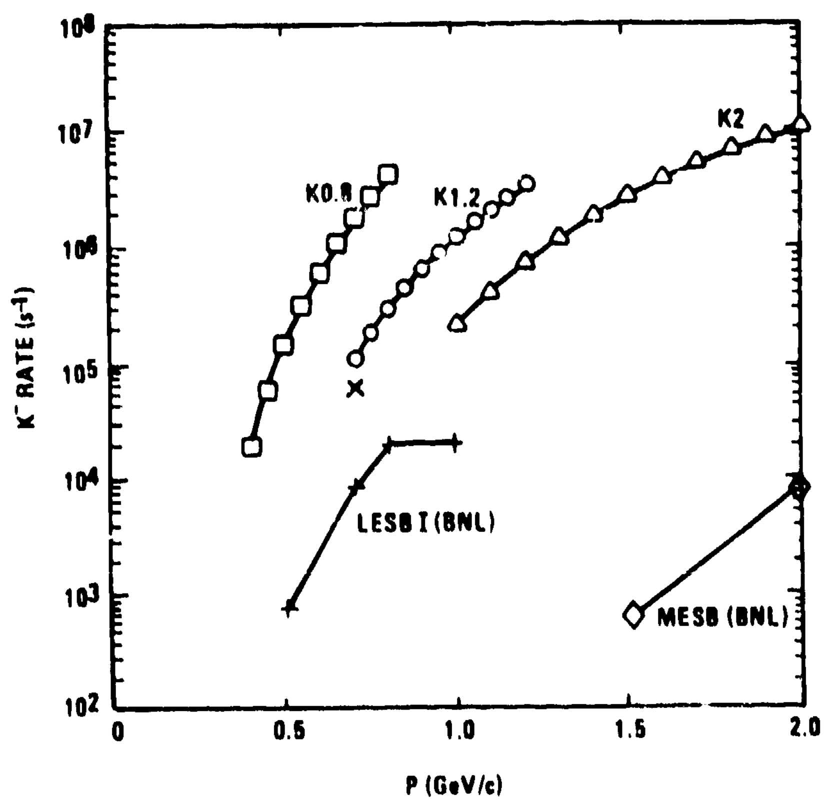


Fig. 16. Low-energy K^- beam rates at LAMPF II compared with those at today's AGS under typical operating conditions.

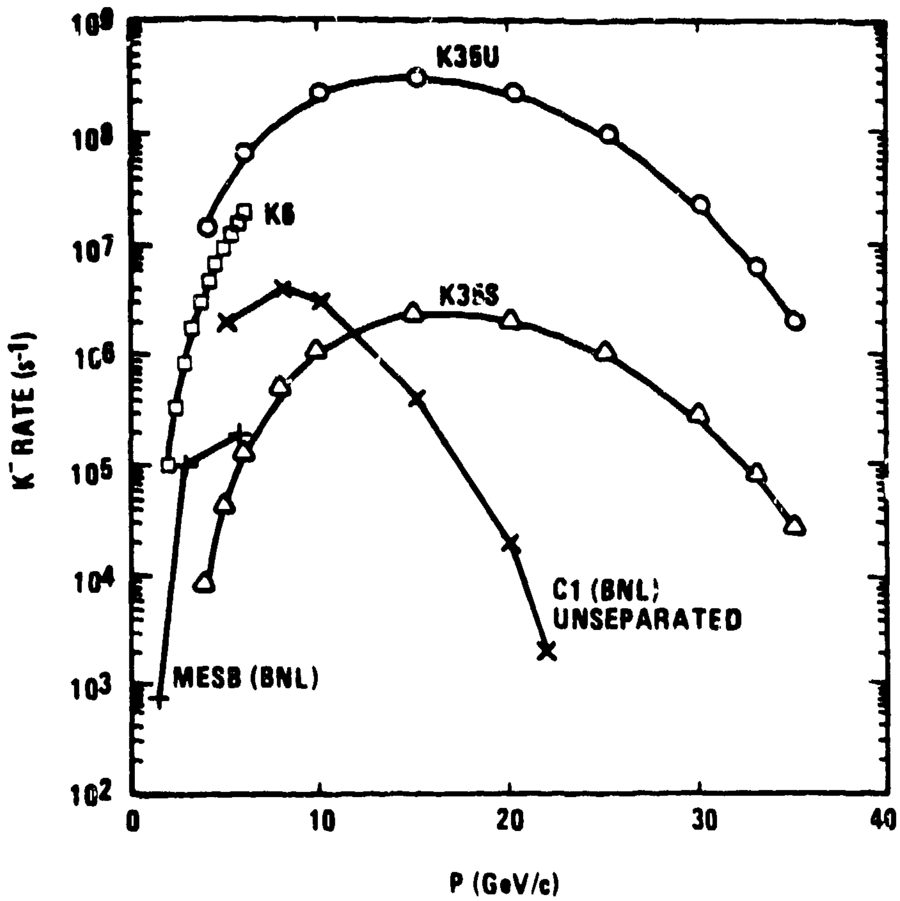


Fig. 17. High-energy K^- beam rates at LAMPF II compared with those at today's AGS under typical operating conditions.

Beam purity is a very important parameter for the intense beams planned at the kaon factories. The calculated π^-/K^- ratio for the LAMPF II kaon beams is plotted in Figs. 18 and 19. The design goal was a ratio better than 1:1 and the calculations show that should be achieved except for the very lowest momenta in K6. For comparison, the reported value of this ratio for MESB II (BNL) for 700 MeV/c is about 20 compared with about 0.14 expected for the LAMPF II beams, K0.8 or K1.2. For MESB at 4 GeV/c, the reported π^-/K^- ratio is about 3 compared with about 0.28 expected for K6 at LAMPF II.

The K^+/K^- ratio for 0^o production is plotted as function of kaon momentum in Fig. 20. It shows that the rates for K^+ will be about a factor of three higher than the corresponding rates for K^- except at the high-momentum end of the spectrum where the K^+ rate is significantly higher. The K_L^o spectrum at the end of the K^o beam line is shown in Fig. 21. It peaks at about 5×10^7 K_L^o per second per GeV/c. The total K_L^o rate integrated over momentum is about 10^9 K_L^o per second.

Fig. 18. π^-/K^- ratio for low-energy beams at LAMPF II.

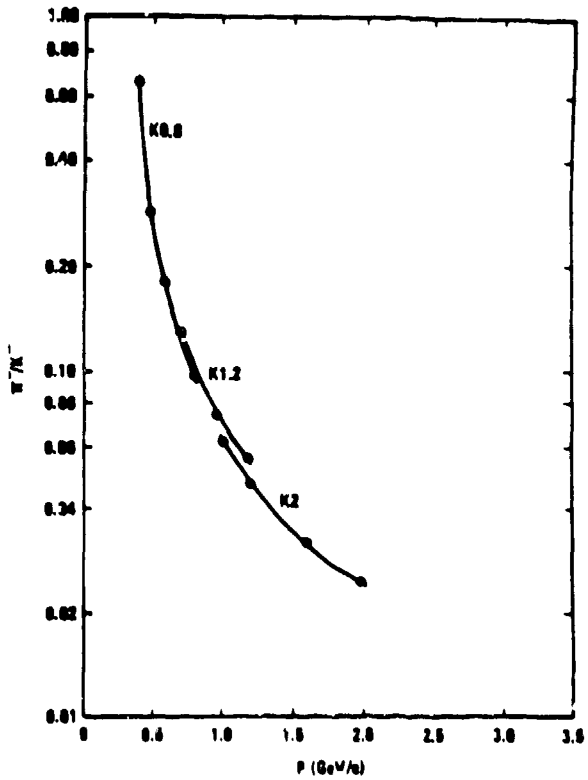
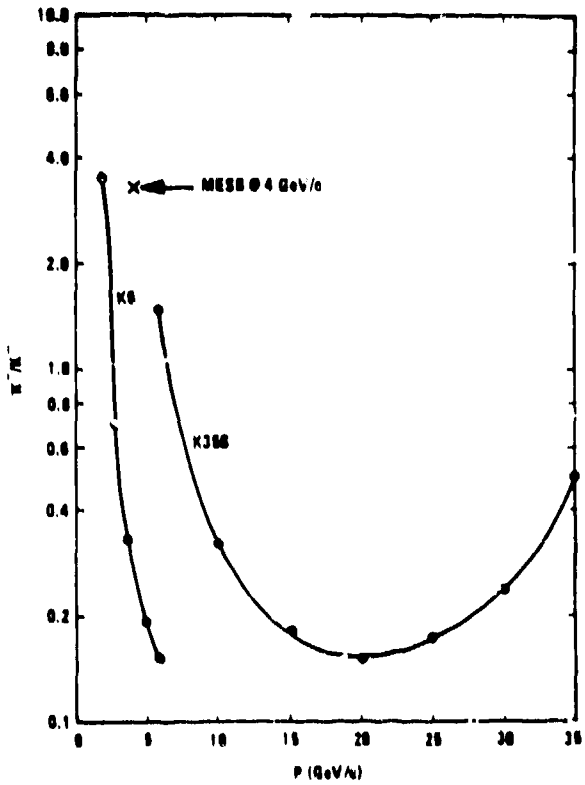


Fig. 19. π^-/K^- ratio for high-energy beams at LAMPF II.



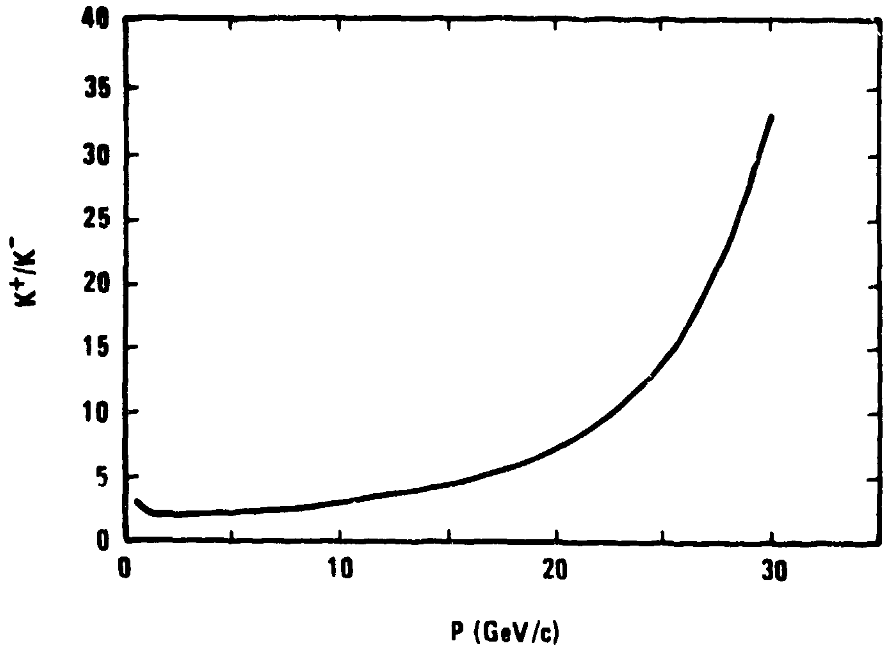


Fig. 20. K^+/K^- ratio (0^o) for 45-GeV primary beam.

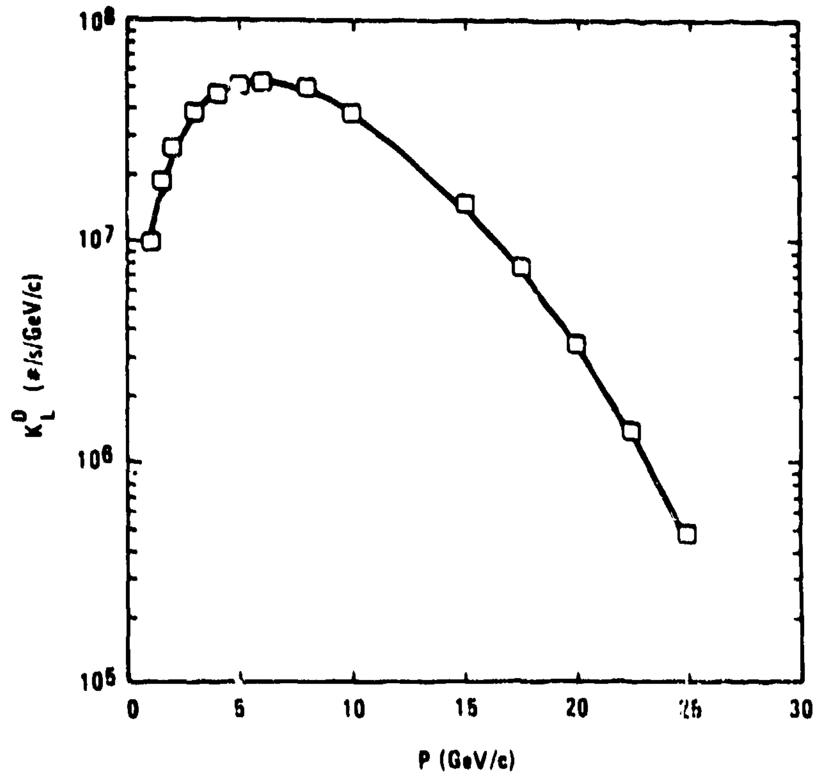


Fig. 21. K_L^o spectrum for the K^o beam at LAMPF II under typical operating conditions.

The rates for other particle species (antiprotons and pions), assuming typical operating conditions, are shown in Figs. 22 through 25. The rates for antiprotons are comparable to K^- while those for pions are two to three orders of magnitude higher and can be as high as 10^{10} pions per second in the unseparated branch of K35.

I will mention briefly the experimental area capabilities planned for the other proposed kaon factories in so far as they are known at this time. The proposed layout of the experimental hall for TRIUMF II is shown in Fig. 26. The fast-extracted beam strikes a target at the neutrino facility in one corner of the hall. Four slow-extracted primary beam lines with one thick target for each provide the beam for the secondary lines. K1, K3, and K5 would be the first beam lines to be implemented. A summary of parameters for the initial beams are shown below in Table IV.

Table IV. Summary of initial charged particle beams for TRIUMF II.

	p_{min}^{max} (GeV/c)	$(\frac{\Delta p}{p})_{max}$ (%)	ℓ (m)	ℓ_s^* (m)	Unsep. flux ($\times 10^6$/s) K^-	K^+	π^-	π^+	$\bar{p}$
K1	6	2	100	30	5	10	500	10^3	6
	3.5				0.5	1	300	500	
K3	1.4	4	43	8	80	150	$2.5\cdot 10^4$	$3.5\cdot 10^4$	40
	0.9				6	11	10^4	$1.4\cdot 10^4$	
K5	0.8	5	18	3	36	60	$2.7\cdot 10^4$	$3.5\cdot 10^4$	6
	0.55				3	6	$1.3\cdot 10^4$	$1.6\cdot 10^4$	

Calculated K^- beam rates for typical operating conditions of 33 μA at 30 GeV incident on thick target (30% of protons interact) are shown in Fig. 27 as a function of momentum for several secondary beam channels. They are comparable to those expected at LAMPF II.

Fig. 22. Low - energy antiproton rates for LAMPF II beams under typical operating conditions.

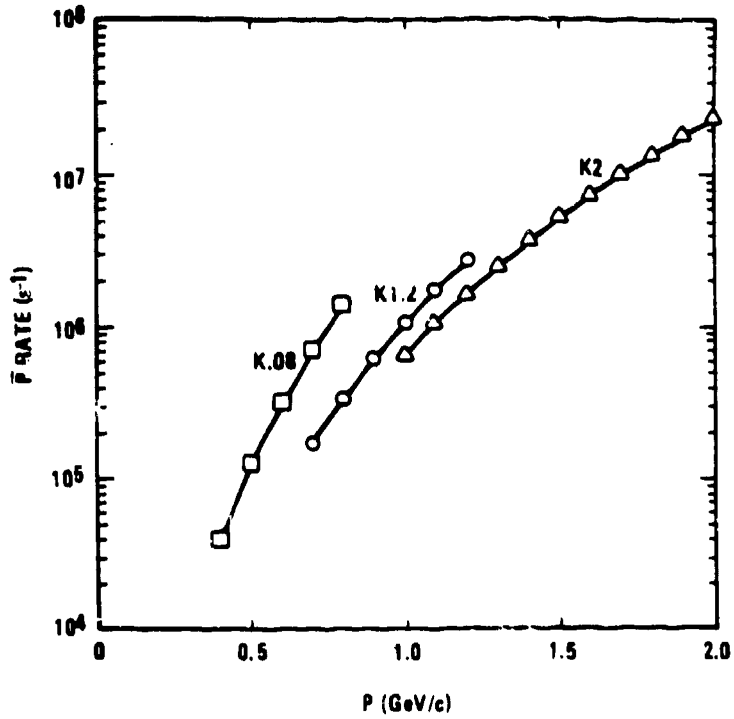


Fig. 23. High -energy antiproton rates for LAMPF II beams under typical operating conditions.

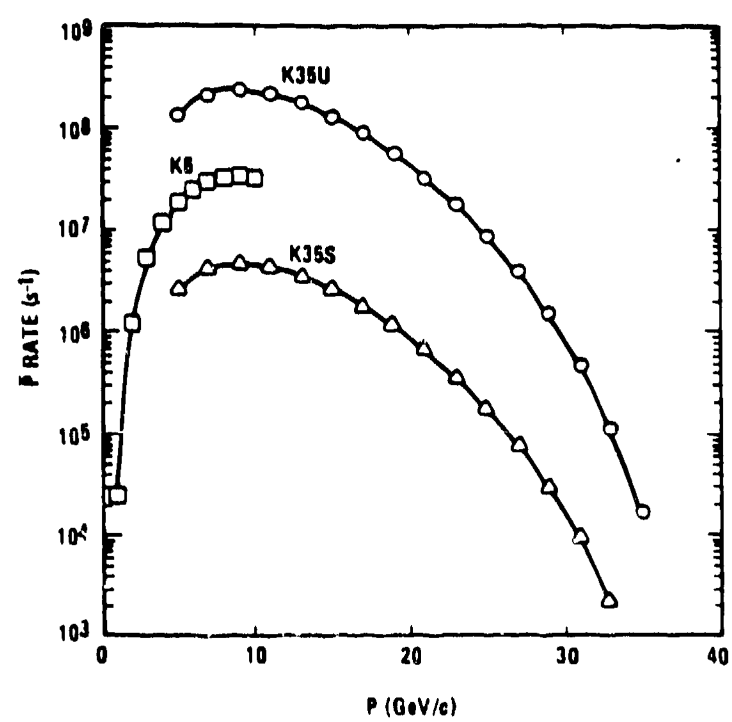


Fig. 24. Low-energy π^- beam rates for LAMPF II beams under typical operating conditions.

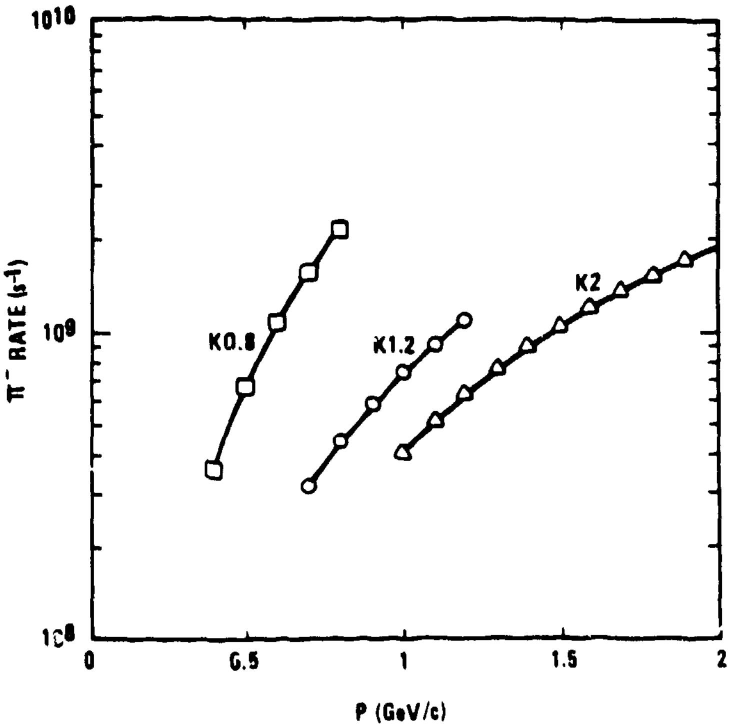
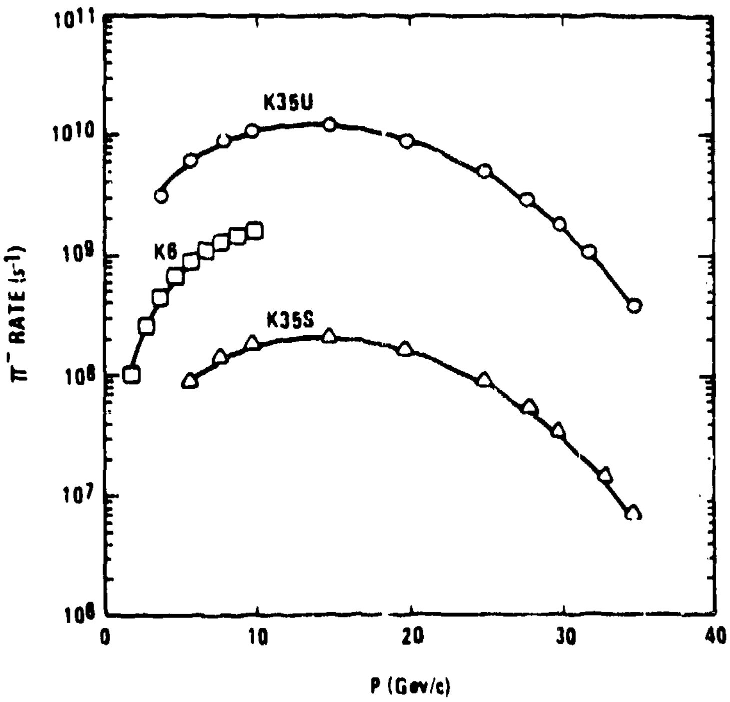


Fig. 25. High-energy π^- beam rates for LAMPF II beams under typical operating conditions.



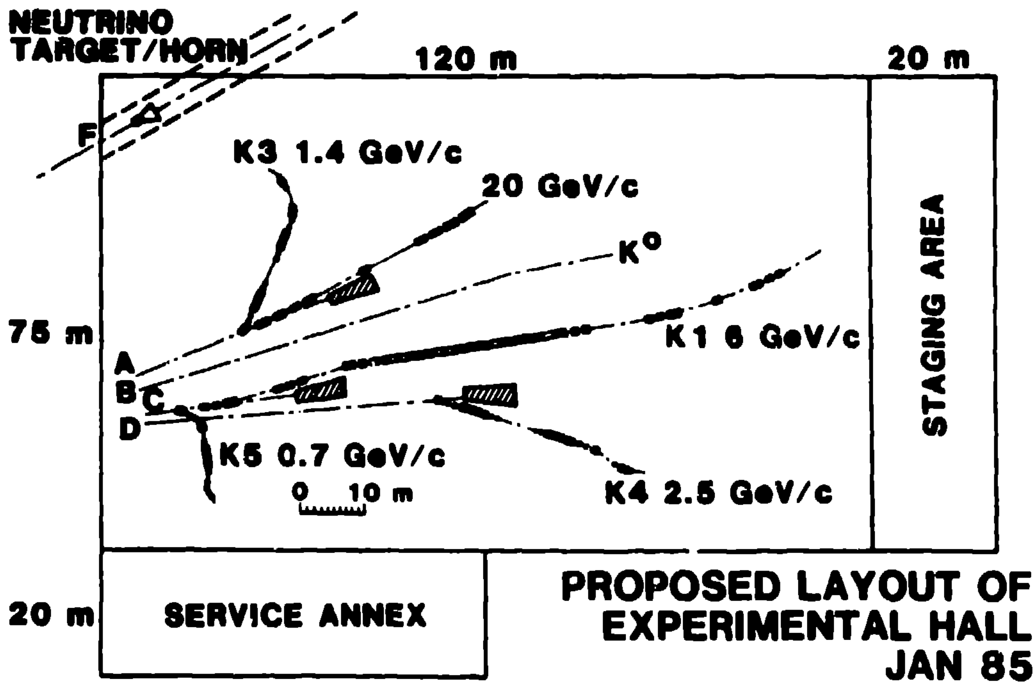
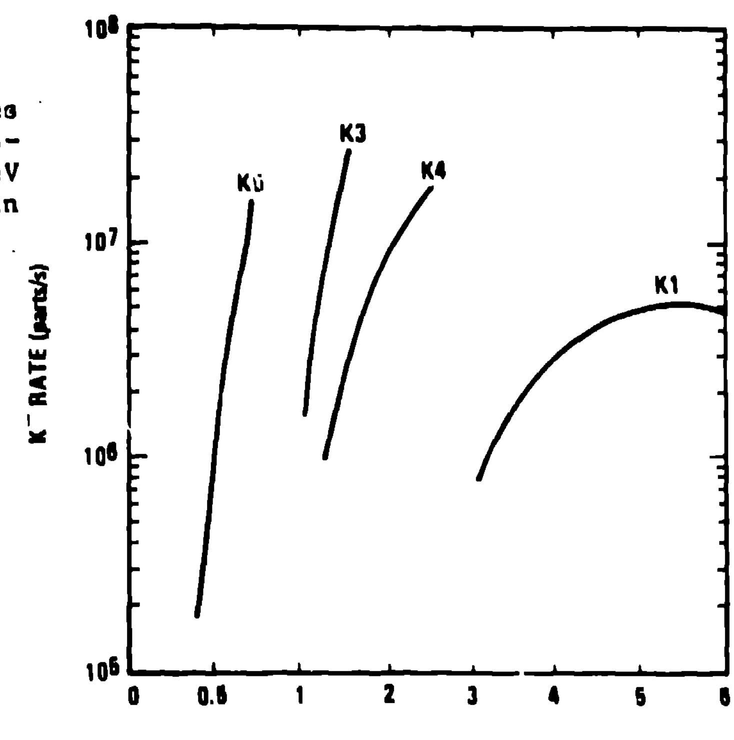


Fig. 26. Layout of TRIUMF II experimental hall.

Fig. 27. K^- beam rates for TRIUMF II beams assuming 33 μA at 30 GeV with 30% interacting in the target.



A schematic layout for the slow-extracted beam area proposed for SIN II is shown in Fig. 28. The configuration is quite different than that proposed for TRIUMF II. Here there is only one primary beam and all targets are in series along the primary beam line. In common with TRIUMF II and LAMPF II, there would be generally two charged-particle secondary beams per target. A similiar choice of secondary beams has also been made. One unique exception is a long, high-energy, decay channel. It serves either as a muon channel or as a time-separated antiproton channel. A 6.5-m Be absorber will remove pions from the muon beam and is expected to give a π/μ ratio of about 10^{-6}. A summary of the beam parameters for the beams suggested for SIN II are given in Table V below.

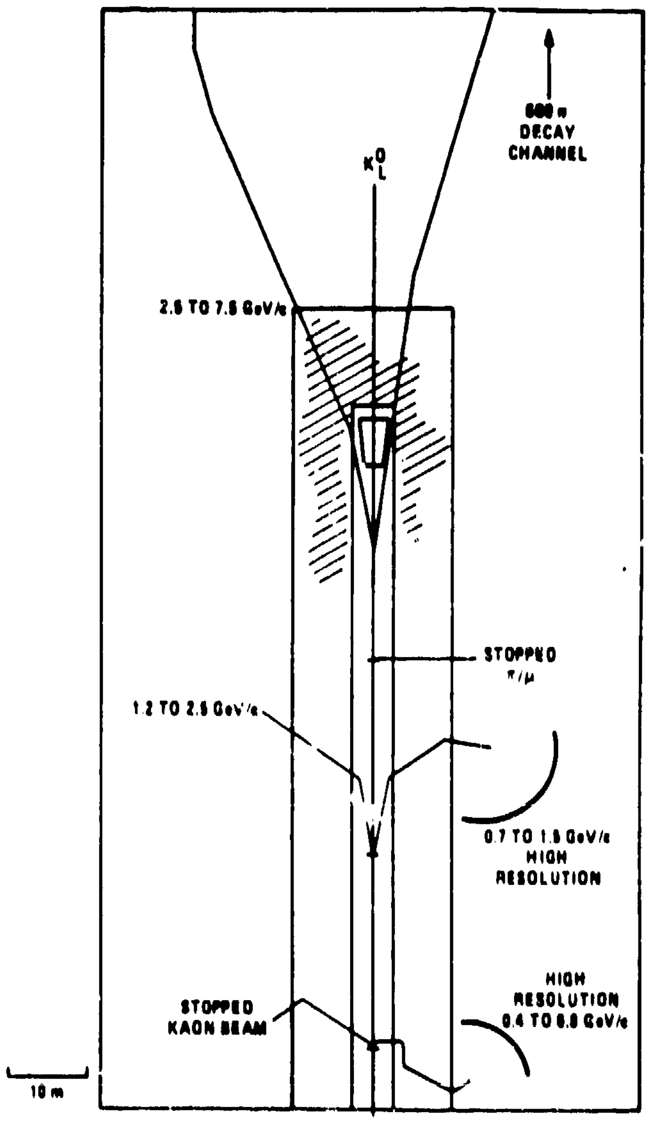


Fig. 28. SIN II experimental area plan.

Table V. SIN II beams.

momentum range (GeV/c)	momentum accept. FWHM	resolution FWHM	length (m)	solid angle (msr)	spot size (cm^2)	flux per sec	beam purity
0.4 to 0.8	4%	$2\ 10^{-3}$	17.5	4	0.6x1.0	K^+ 10^6 K^- $5\cdot 10^5$	$\pi/K > 1$
0.4 to 0.8	6%	10^{-2}	14.5	7	1.0x1.5	K^+ $5\cdot 10^6$ K^- $2.5x10^6$	$\pi/K > 1$
0.7 to 1.5	2%	$6\ 10^{-4}$	26.5	2.5	0.3x0.3	K^+ $6\cdot 10^6$ K^- $3\cdot 10^6$	π/K^{-2}
1.2 to 2.5	6%	10^{-2}	32	1.5	0.5x0.5	K^+ 10^7 K^- $5\cdot 10^6$	π/K ~1
							(6.6m Be)
4 to 13	6%	$5\ 10^{-3}$	750	0.6 to	6 x 6	μ^+ $5\cdot 10^8$	π/μ 10^{-6}
1 to 6	1% 6% 6%	10^{-3} 10^{-2} 10^{-2}	750	1.2	4 x 4	$\bar{p}$ $2\cdot 10^6$ p $3\cdot 10^8$ p $2\cdot 10^8$	10^{-3} $\pi^-/\bar{p}$ 3 20
2.5 to 7.5	6%	10^{-2}	90	0.4	1x1.5	K^+ $8\cdot 10^7$ K^- $3\cdot 10^7$	π/K~3(4)
							(3.5m C absorber)
K^0_L (0°)			50	0.01	15x15	K^0_L 10^7	K^0_L/n~1
stopped π/μ	equivalent to 1 μA protons at 600 MeV						

A very preliminary layout of the slow-extracted beam area for the Kyoto kaon factory is given schematically in Fig. 29. There would be two primary beam lines with two targets per primary beam line, much like the configuration for LAMPF II. The planners at Kyoto, however, show more secondary beam lines with greater emphasis on muon beams and stopping kaon beams.

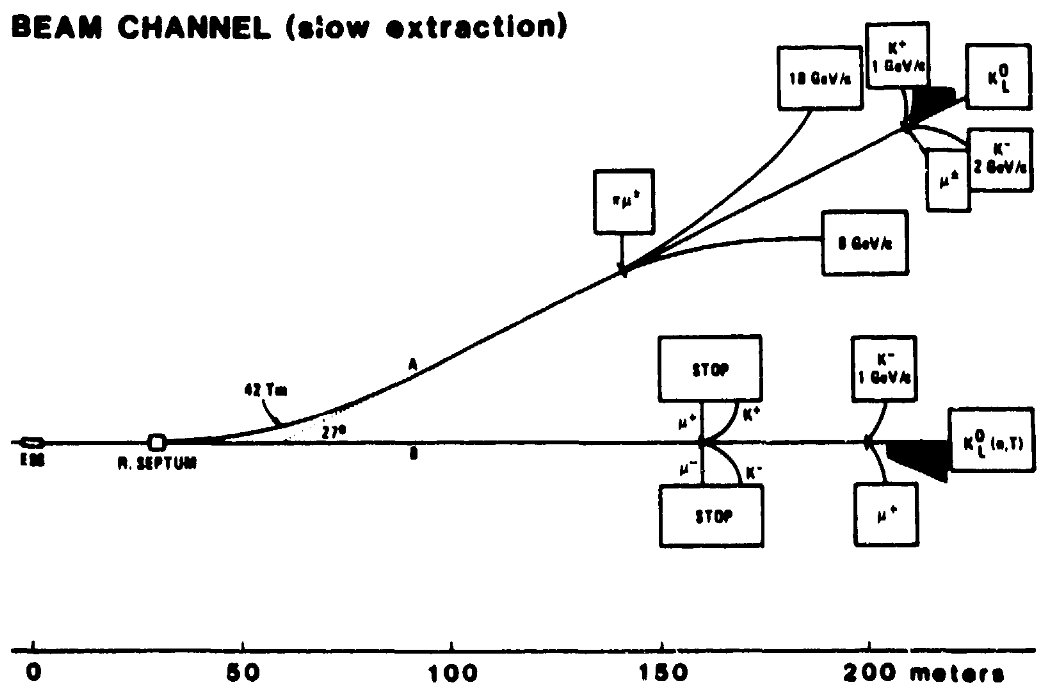


Fig. 29. Proposed experimental areas for the Kyoto kaon factory.

In spite of the difficulty of trying to be completely fair while at the same time brief and concise, I will try to summarize the comparison of the several kaon factories with just a very few numbers. Table VI shows a comparison of the estimated annual yield of K^-, antiprotons, and ν_μ for LAMPF II, TRIUMF II, and SIN II in units to today's AGS.

Table VI. Estimated relative annual yields of several kaon factories. (AGS 1984 = 1)

	K^-/year (7 GeV/c)	$\bar{p}$/year (7 GeV/c)	ν_μ/year
LAMPF II	193	302	112
TRIUMF II	161	176	100
SIN II	46	35	33

COSTS

LAMPF II is the only kaon-factory proposal for which a cost estimate can be discussed in this presentation. The estimate was prepared jointly by LAMPF staff and by a team from Science Applications International Corporation (SAIC) lead by Paul Reardon and Maurice Sabado. The SAIC team had just finished work on the SSC cost estimate and were in a good position to provide expert assistance to the LAMPF II effort. The Los Alamos work breakdown structure was used; the majority of items were independently checked. Rules of thumb based on recent experience with large accelerator projects were used to estimate installation at 19%, project management at 11%, and contingency at 25%. A simplified summary of costs is provided in Table VII below. The last column gives the total cost including contingency, installation, and project management. Typically, the total cost including all the above mentioned factors is about double the cost of the hardware or material. The grand total for LAMPF II is 452 million dollars of which about 60% is for the accelerators and 40% for the experimental facilities but not including major detectors.

Table VII. Simplified summary of LAMPF II costs.

	Material	Material + Labor	Total Cost
6 GeV			
Conventional Construction	-	\$ 29.1 M	\$ 45.0 M
Accelerator	\$ 35.6 M	-	75.0
Experimental Facilities	14.9	-	29.0
		Subtotal	\$149.0 M
45 GeV			
Conventional Construction	-	\$ 25.7 M	\$ 40.0 M
Accelerator	\$ 67.3 M	-	120.0
Experimental Facilities	75.0	-	143.0
		Subtotal	\$303.0 M
		Grand Total	\$452.0 M

CONCLUSIONS

The seven proposed facilities reviewed in this paper are the manifestation of a strong and growing interest in and enthusiasm for the kaon - factory concept. Facility designers are making rapid progress in developing sound proposals. Much has been accomplished to establish the scope of these projects, but much remains to be done before conceptual designs are completed. Now is the experimenter's "window of opportunity" to influence the facility designs. Science budgets will not permit the provision of facilities optimized for every worthwhile experiment, but with thoughtful and timely input from potential users, perhaps we can make better initial choices.

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